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VARIABLE DYNAMIC DIRECT-CURRENT BRAKE CIRCUIT FOR A.C.MOTOR

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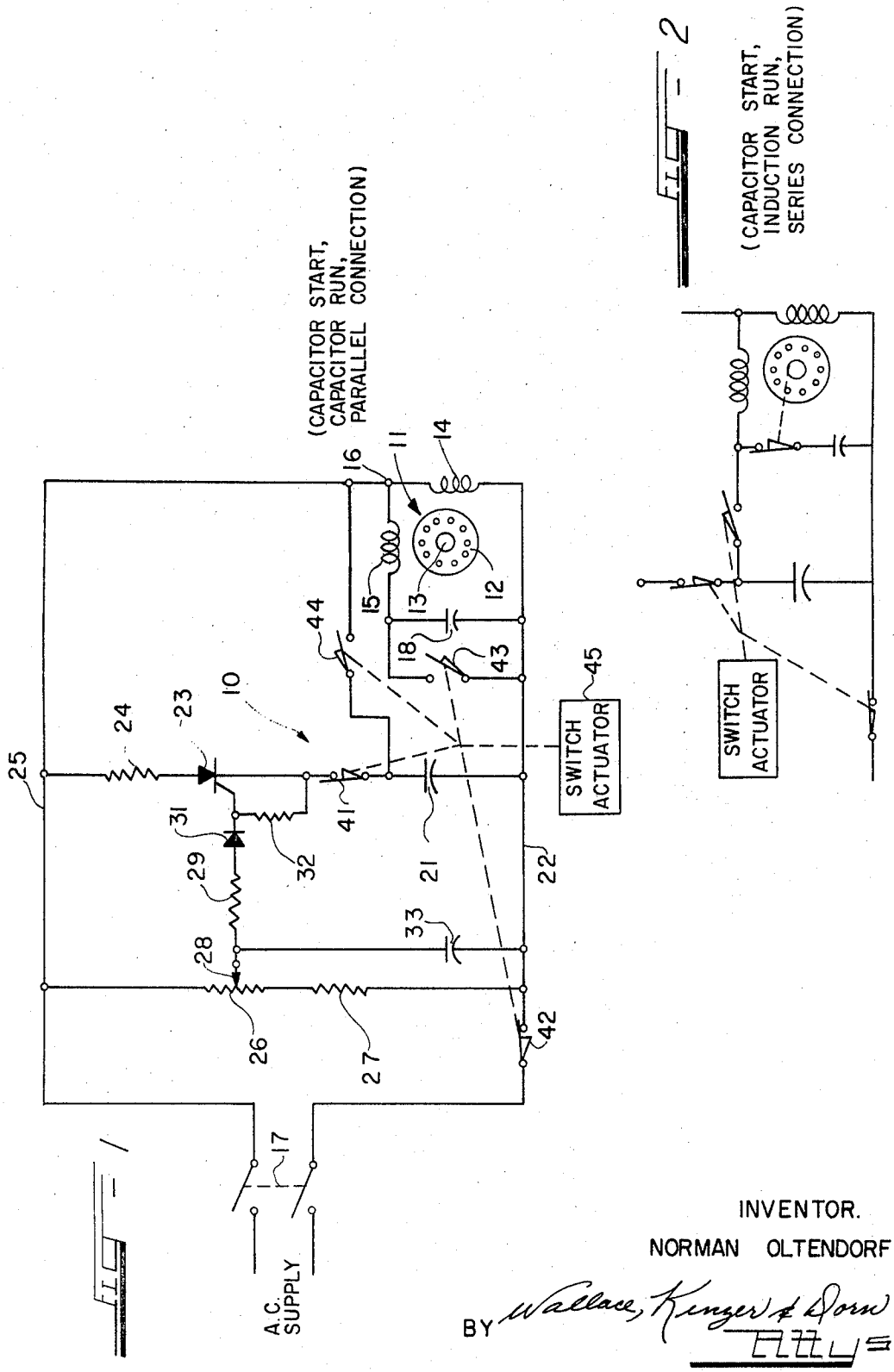


FIG - 1

FIG - 2

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VARIABLE DYNAMIC DIRECT-CURRENT BRAKE CIRCUIT FOR A.C. MOTOR

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ABSTRACT OF THE DISCLOSURE

A variable dynamic direct-current brake circuit for an AC electric motor that permits stopping the motor, under predetermined load, within a preselected time that can be adjusted over a broad range. A relatively large brake storage capacitor is connected in a charging circuit coupled to the AC supply for the motor. The charging circuit provides for adjustment of the maximum charge on the brake capacitor; it includes a signal-controlled rectifier connected in series with the brake capacitor. The rectifier is gated by a phase-shift circuit that may be adjusted to control the firing angle of the rectifier, thus varying the maximum voltage, up to approximately the peak line voltage, to which the brake capacitor can be charged. For braking, the brake capacitor is disconnected from the charging circuit and connected to the motor field windings to afford dynamic direct-current braking, with the braking rate and time determined by the charge on the brake capacitor.

Background of the invention

There are several known methods for electrical braking of alternating current motors. A concise summary of various forms of electrical brakes is set forth in International Rectifier News for February-March 1957 in an article entitled "Direct Current Braking for AC Induction Motors." Known methods include plugging in which electrical power is applied to the motor in reverse phase rotation to develop a reverse torque, dynamic braking in which is resistive load is shunted across the motor terminals, capacitor braking in which capacitors are connected across two or three phases of an induction motor, re-generative braking applied to a motor driven above its synchronous speed, and direct current braking effected by applying a direct current to the field winding of an AC motor. The present invention relates to a new and improved form of direct current braking and is referred to as a variable direct current dynamic brake system.

In direct current braking for alternating current motors, as known heretofore, it has been customary to provide a rectifier circuit that can be connected to two of the motor terminals to supply a direct current to at least a portion of the motor field windings when braking is desired. At the same time, of course, the normal connection of the motor terminals to the AC supply is broken. The rectifiers employed in a circuit of this kind may be required to carry relatively high currents, since the current required for effective braking often exceeds 200% of the motor full load ampere rating. Variation of the braking rate can be achieved, usually by provision of an adjustable auto transformer or some other variable impedance ahead of the rectifiers in the DC circuit. It has also been proposed to utilize a storage capacitor in the brake circuit, instead of a direct rectifier circuit.

In many applications, and particularly for relatively small single phase motors, the cost of a direct rectifier circuit to afford direct current braking is frequently excessive in relation to the cost of the motor itself. On the other hand, capacitor discharge circuits for DC braking, if economically constructed for a single motor size, have afforded no convenient means for adjusting the braking rate of the apparatus. Adjustable capacitors, in the sizes necessary for braking of any motor of reasonable size, are prohibitively expensive. Furthermore, since the peak voltage to which the capacitor may be charged is limited by the AC line voltage available, unless the added expense of a transformer is engendered, it is not practical to construct a single brake circuit that is usable with a variety of different motor sizes. Consequently, direct current braking has seen relatively limited application.

Summary of the invention

It is a primary object of the invention, therefore, to provide a new and improved variable direct current dynamic brake circuit for an alternating current electric motor that affords close and accurate control of the braking rate of the motor.

Another object of the invention is to provide a variable direct current dynamic brake circuit for an alternating current motor that permits adjustment of the braking rate for the motor over a wide range yet is simple and inexpensive in construction and requires no adjustable transformers.

A further object of the invention is to afford a new and improved variable direct current dynamic brake circuit for an alternating current motor that is controlled, in its operation, by a single signal-controlled rectifier that may have a relatively low current and voltage rating.

Another important object of the invention is to provide a new and improved variable direct current dynamic brake circuit for an alternating current motor that may be employed with a variety of different motors of varying characteristics.

Accordingly, the invention relates to a variable direct current dynamic brake circuit for an alternating current electric motor having a rotor and a field winding, the field winding being connectible to an AC supply. The brake circuit comprises a relatively large brake capacitor and a charging circuit connected to the AC supply for the motor and to the brake capacitor, the charging circuit including a signal controlled rectifier. The charging circuit includes adjustable means for varying the conduction angle of the signal-controlled rectifier, thereby adjusting the charge on the brake capacitor. The brake circuit further includes switching means for disconnecting the brake capacitor from the charging circuit, for disconnecting the motor field winding from its AC supply, and for substantially simultaneously connecting the brake capacitor to the field winding to discharge the brake capacitor through the field winding and brake the motor at a rate and within a time determined by the total charge on the brake capacitor.

Other and further objects of the present invention will be apparent from the following description and claims and are illustrated in the accompanying drawings which, by way of illustration, show a preferred embodiment of the present invention and the principles thereof and what is now considered to be the best mode contemplated for applying these principles. Other embodiments of the invention embodying the same or equivalent principles may be made as desired by those skilled in the art without departing from the present invention.

Description of the drawing

FIG. 1 is a schematic circuit diagram of a variable direct current dynamic brake circuit constructed in accordance with one embodiment of the present invention; and

FIG. 2 illustrates a modification of the brake circuit of FIG. 1 in accordance with another embodiment of the invention.

Description of the preferred embodiments

FIG. 1 illustrates a variable direct current dynamic brake circuit 10 for the controlled braking of an alternat-

ing current electric motor. In FIG. 1, the brake circuit **10** is applied to a single phase capacitor-start capacitor-run motor **11** comprising a conventional squirrel cage rotor **12**, mounted upon a motor shaft **13**. Motor **11** further includes two field windings, a starting winding **15** and a running winding **14**, these two windings being electrically connected to each other at a common terminal **16**.

The common terminal **16** of the two field windings for motor **11** is connected to one pole of a single-pole double-throw switch **17** that is connected to a suitable alternating current supply. The other terminal of running winding **14** is connected to the other pole of the starting switch **17**. The remaining terminal of the starting winding **15** is connected to a capacitor **18** that is also returned to the second pole of starting switch **17**.

Motor **11** is of conventional construction and its operation is conventionally controlled by starting switch **17**, which could be replaced by a conventional electrically actuated motor contactor if desired. Closing of switch **17** energizes the two field windings **14** and **15**. The currents in the two windings are dephased somewhat with respect to each other due to the presence of the capacitor **18** in the circuit for winding **15**. Thus, a rotating electrical field is established by the windings **14** and **15**, energizing the squirrel cage rotor **12** and causing the motor to rotate.

The variable direct current dynamic brake circuit **10** in the embodiment of FIG. 1 comprises a relatively large brake capacitor **21**. Capacitor **21** is connected in a charging circuit energized from the same AC supply as motor **11**. Thus, one terminal of capacitor **21** is connected to the conductor **22** that connects the separate terminals of windings **14** and **15** to starting switch **17**. The other terminal of capacitor **21** is connected to the cathode of a signal controlled rectifier **23**. The anode of rectifier **23** is connected through a resistor **24** to the AC supply line **25** that connects the motor field winding terminal **16** to starting switch **17**.

The charging circuit for brake capacitor **21** further includes an adjustable means for varying the conduction angle of the signal controlled rectifier **23** to adjust the charge on the brake capacitor, as described more fully hereinafter. This adjustable means comprises a potentiometer **26** and a resistor **27** connected in series with each other across the AC supply lines **25** and **22**. The tap **28** of potentiometer **26** is connected to the gate electrode of rectifier **23** by a circuit that includes, in series, a resistor **29** and a blocking diode **31**. A load resistor **32** is connected between the gate electrode and the cathode of rectifier **23**. A capacitor **33** is connected from potentiometer tap **28** to conductor **22** to afford, with potentiometer **26**, a phase shift circuit for shifting the phase of the signal supplied to the gate electrode of rectifier **23** relative to the phase of the AC signal in the anode-cathode path of the rectifier.

Brake circuit **10** further includes switching means for control of the braking operation. This switching means comprises four individual switches **41**, **42**, **43** and **44** all actuated from a single switch actuator mechanism **45**. The first switch **41** of this switching means is a normally closed switch that is interposed in the circuit between capacitor **21** and the cathode of rectifier **23**. The second switch **42** is interposed in series in the line conductor **22**, between starting switch **17** and the operating components of the motor and the brake circuit. The third switch **43** is a normally open switch connected in shunt with the operating capacitor **18** of the motor. The fourth switch **44** is connected from capacitor **21** to the common terminal **16** of the motor field windings.

In considering operation of the variable direct current dynamic brake circuit **10**, it may first be assumed that switch **17** has been closed, energizing motor **11**. It may further be assumed that the motor **11** is operating under some predetermined load. During the time that motor **11** is running, brake capacitor **21** is charged to a voltage level that is determined by the setting of the brake control potentiometer **26**.

The charging level of brake capacitor **21** is determined in accordance with the phase shift of the gate signal supplied to rectifier **23** through the phase shift circuit comprising potentiometer **26** and capacitor **33**. Thus, by varying the setting of the potentiometer tap **28**, the degree of phase shift effected by the phase shift circuit may be varied from approximately 90° to approximately 170°. With potentiometer **26** adjusted for maximum resistance, by moving tap **28** to the end of the potentiometer adjacent resistor **27**, maximum phase shift is obtained and rectifier **23** is fired or rendered conductive near the end of each cycle in which the anode of the rectifier is driven positive with respect to its cathode. On the other hand, movement of tap **28** to the opposite end of the potentiometer to decrease the effective resistance of the phase shift circuit reduces the amount of phase shift so that the rectifier is rendered conductive nearer the 90° point in each cycle, which coincides with the peak of the AC line voltage. With tap **28** of potentiometer moved to the upper end of potentiometer **26** as seen in FIG. 1, the phase shift circuit resistance is at a minimum, the rectifier is fired near the 90° point, and maximum charge is established on capacitor **21**.

With the circuit illustrated, assuming a supply voltage of 120 volts, the maximum charge on brake capacitor **21** is near the peak of the line voltage. Typically, the maximum charge may be approximately 165 volts. The minimum charge is much lower. In a typical circuit, again assuming a line voltage of 120 volts, the minimum charge on brake capacitor **21** may be of the order of 25 volts.

For any particular setting of potentiometer **26**, brake capacitor **21** is charged to a voltage level that is determined by the firing angle of the signal controlled rectifier **23**. A number of cycles of the AC supply may be required to produce a charge on capacitor **21** that corresponds to the voltage level for which the circuit is set. However, once phase voltage level is reached, on capacitor **21**, the signal controlled rectifier **23** will be fired only occasionally, automatically maintaining the desired voltage level. Thus, once the charge on the brake capacitor **21** reaches the same potential as the instantaneous voltage level of line **25**, at the time the rectifier is triggered to its conductive condition, there is essentially no conduction through the rectifier because there is no voltage drop across the rectifier. For conduction through the rectifier, its anode must be at least a few volts positive with respect to its cathode. As leakage current lowers the charge on brake capacitor **21**, the voltage on the brake capacitor is reduced to a point at which there is a sufficient voltage differential between the anode and cathode of rectifier **23** to cause the rectifier to conduct. Under these circumstances, continuing conduction of the rectifier for a few cycles again builds up the charge on brake capacitor **21**, following which the rectifier remains idle for an additional period. At any given time, the charge on capacitor **21** is approximately constant, the voltage differential required for conduction in rectifier **23** being quite small.

Resistor **29** and diode **31** are incorporated in the charging circuit primarily for protection of the other circuit components. Thus, resistor **29** is a relatively large resistor that limits the gate current to rectifier **23**. Diode **31** prevents a reverse voltage between the gate electrode and the cathode of the signal controlled rectifier, which could damage the rectifier. In addition, resistor **24** is incorporated in the circuit primarily to limit the charging current through rectifier **23** and capacitor **21**.

Initiation of the braking action is accomplished by the substantially simultaneous action of all of switches **41–44** by means of switch actuator **45**. In a typical application, switches **41–44** may comprise a limit switch assembly actuated when a part of a machine tool, a con-

veyor, or some other apparatus reaches a point near the end of its intended travel and requires braking. In an application of this kind, switch actuator **45** may comprise a lever or other mechanical lever for physically throwing switches **41–44**. On the other hand, the switch actuator may constitute a sensing element of one form or another for actuating a relay, in which case switches **41** and **42** constitute normally closed contacts of the relay and switches **43** and **44** are normally open relay contacts.

Upon operation of switch actuator **45**, switch **41** opens, disconnecting brake capacitor **21** from its charging circuit. At the same time, switch **42** opens, disconnecting the normal operating circuit to the field windings of motor **11** by opening line **22**. Switch **44** closes, connecting brake capacitor **21** to the common terminal **16** of field windings **14** and **15** and establishing a direct current through winding **14** as the capacitor discharges. Furthermore, switch **43** closes, so that winding **15** is connected directly in parallel with winding **14** and also receives a direct current. The direct currents through field windings **14** and **15** exert a positive braking effect on motor **11**, in accordance with Lenz' law.

The energy stored in brake capacitor **21**, when charged to a given voltage V determined by the setting of potentiometer **28**, may be expressed as

$$E=\frac{CV^2}{2}$$

Thus, it is seen that the brake energy available from capacitor **21** is directly proportional to the capacitance, which is a fixed parameter, and to the square of the voltage, which is the variable or adjustable parameter for circuit **10**. Adjustment of potentiometer **26**, as described above, and the corresponding adjustment of the firing angle of rectifier **23**, varies the voltage to which capacitor **21** is charged. This effectively adjusts both the braking rate and the braking time for motor **11**.

The circuit illustrated in FIG. 2 is a modification of FIG. 1, applied to a somewhat different motor **111**. Thus, motor **111** comprises a conventional squirrel cage rotor **12** mounted upon a shaft **13** having a main winding **14** and a starting winding **15** with the two windings connected together at the common terminal **16**. As before, terminal **16** is connected to the power line conductor **25**. Moreover, the running winding **14** is again connected directly to the power line **22**. In this instance, however, the starting winding **13** is connected to a centrifugally actuated switch **112** that is returned to conductor **22** through a starting capacitor **118**.

From the foregoing description, it will be seen that motor **111** is a conventional capacitor start inductance run motor. When the motor is started, winding **15** is maintained in the operating circuit for the motor, switch **112** being closed. The centrifugal switch **112** opens when the motor approaches its rated speed, disconnecting winding **115** from the motor circuit.

In FIG. 2, brake capacitor **21** is again connected to the charging circuit, which may be the same as illustrated in FIG. 1, by the normally closed switch **41**. Furthermore, the normally closed switch **42** is again incorporated in power line **22** and both of these switches are actuated by a single switch actuator **45**.

In the circuit of FIG. 2, however, the connection from brake capacitor **21** to the motor windings for effecting a braking operation is somewhat different from the connection afforded by switch **44** in FIG. 1. Thus, a normally open switch **44A**, in FIG. 2, connects brake capacitor **21** to the terminal of starting winding **15** opposite the terminal **16**.

The operation of the circuit arrangement of FIG. 2 is essentially the same as described above in connection with FIG. 1. The principal difference is that, during a braking operation, with switches **41**, **42** and **44A** actuated, the two motor windings **14** and **15** are connected in series with each other across brake capacitor **21**. This is in contrast with the parallel connection shown in FIG. 1. It should be noted that the series connection for the field windings illustrated in FIG. 2 can also be applied to a capacitor run motor such as the motor **11** of FIG. 1. Conversely, the parallel connection illustrated in FIG. 1 can be employed with an induction run motor such as motor **111**. Moreover, either of the two brake circuits can be employed with split phase motors and other motors in which direct current braking is practically employable.

The variable dynamic direct current brake circuits of the present invention afford sensitive and accurate control for the braking rate and the braking time of alternating current motors with which they are employed. The brake circuits are relatively simple and inexpensive and adjustment of the brake rate is effected with a simple and inexpensive potentiometer. There is no requirement for variable auto-transformers or other relatively complex and expensive adjusting means. The signal controlled rectifiers that constitutes the principal control elements for the charging circuits can have relatively low current and voltage ratings. Moreover, a single circuit can be constructed to function with motors of varying sizes and ratings, merely by substituting capacitors of different size for the brake capacitor **21**. Indeed, capacitors of the same rating can be employed for a substantial range of motor sizes.

In order to afford a more complete illustration of the invention, specific circuit data for the embodiment illustrated in FIG. 1 are set forth hereinafter. It should be understood that this information is provided merely by way of illustration and not as a limitation on the invention.

Circuit component:	Rating or type
Capacitor **21**, microfarads	500
Rectifier **23**	Type C106
Resistor **24**, ohms	47
Potentiometer **26**, kilohms	100
Resistor **27**, kilohms	100
Resistor **29**, kilohms	2.2
Diode **31**	Type TS2
Resistor **32**, kilohm	1
Capacitor **33**, microfarads	0.15

The foregoing circuit data apply to a squirrel cage induction motor of relatively small size such as one rated at approximately $\frac{1}{50}$ horsepower.

I claim:

1. A variable direct-current dynamic brake circuit for an alternating-current electric motor having a rotor and a field winding, said field winding connectable to an AC supply, comprising:

a relatively large brake capacitor;

a charging circuit connected to the AC supply for the motor and to said brake capacitor, and including a signal-controlled rectifier;

adjustable means, included in said charging circuit, for varying the conduction angle of said signal-controlled rectifier to adjust the charge on said brake capacitor; and

switching means for disconnecting said brake capacitor from said charging circuit, for disconnecting said field winding from said AC supply, and for substantially simultaneously connecting said brake capacitor to said field winding to discharge said brake capacitor through said field winding to brake said motor at a rate and within a time determined by the total charge on said brake capacitor.

2. A variable direct-current dynamic brake circuit for an alternating-current motor, according to claim **1**, in which said adjustable means comprises a variable phase-shift circuit connected to said AC supply and to the gate electrode of said signal-controlled rectifier.

3. A variable direct-current dynamic brake circuit for an alternating current motor, according to claim **1**, in which said adjustable means comprises a resistance voltage divider connected across said AC supply and including

a potentiometer having a variable tap connected to the gate electrode of said signal-controlled rectifier, and a capacitor connected in parallel with said voltage divider to afford therewith a phase shift circuit, the amount of phase shift effected by said phase shift circuit being determined by adjustment of said potentiometer.

4. A variable direct-current brake circuit for an alternating-current motor, according to claim 3, and further comprising a blocking diode connected between said potentiometer tap and said gate electrode of said signal-controlled rectifier.

5. A variable direct-current dynamic brake circuit for an alternating current motor, according to claim 1, for use with an electric motor including two field windings, in which said switching means connects both of said two field windings to said brake capacitor for braking operations.

6. A variable direct-current dynamic brake circuit for an alternating current motor, according to claim 5, in

which said switching means connects said field windings in parallel with each other across said brake capacitor.

7. A variable direct-current dynamic brake circuit for an alternating current motor, according to claim 6, for use with an electric motor having an operating capacitor connected to one of said field windings, in which said switching means includes means for shunting said operating capacitor during braking operations.

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